

Appendix A¹

Klamath Reservoir Sediment Composition: A Summary and Presentation of Previous Studies.

The California State Coastal Conservancy commissioned a series of studies (GEC 2006; Shannon and Wilson Inc. 2006) in an effort to better understand the volume and compositions of the reservoir deposit in three of the four lower most reservoirs on the Klamath River (i.e., Iron Gate, Copco 1, and J.C. Boyle reservoirs). No studies were conducted for the fourth reservoir, Copco 2 Reservoir, because no sediment deposit was found in that reservoir (GEC 2006). Here we summarize some of the findings reported in these studies (i.e., GEC 2006; Shannon and Wilson Inc. 2006) in a format that can be used directly for the sediment transport analysis reported in this technical memorandum.

There are two sources for the data used in this appendix: physical and chemical composition data obtained by Analytical Resources Inc. (ARI) reported in Appendix E in GEC (2006), and the water content and organic carbon content obtained by Shannon and Wilson Inc. (2006), which is also reported in GEC (2006).

The ARI test results for Iron Gate, Copco 1, and J.C. Boyle reservoirs are summarized in this appendix in Tables A-1, A-2, and A-3, respectively. In these three tables, data in columns 2 and 3 were directly copied from ARI data sheets presented in Appendix E of GEC (2006), and the remaining columns (i.e., columns 4 through 8) were calculated based on the assumptions that (a) the amount of material other than water, solids and organic carbon is small and can be neglected in deriving solid and organic carbon contents in the deposits; (2) water, solids and dry organic carbon have densities of 1,000 kg/m³, 2,650 kg/m³ and 1,100 kg/m³, respectively. The calculations of the data presented in columns 4 through 8 are rather apparent and simple, and thus, are not discussed here.

Tables A-1, A-2 and A-3 also summarize the mean, standard deviation, and maximum and minimum values of the test results. To help better comprehend the information presented in Tables A-1, A-2, and A-3, the summary results for mean values of solids, organic carbon and water contents in the deposits are also presented in two diagrams in Figure A-1, one as mass fractions, and the other as volumetric fractions for solids, organic carbon and water. The solid and organic carbon masses contained in unit volume of deposit are presented in Figures A-2 and A-3, respectively. The solid content of 640 kg/m³ (40 lb/ft³) used for suspended sediment analysis in GEC (2005) is also presented in Figure A-2.

In addition to the test results from ARI provided in Appendix E of GEC (2006), Shannon and Wilson Inc. (2006) also tested five samples, one each from Iron Gate and J.C. Boyle Reservoirs, and three from Copco 1 Reservoir. The Shannon and Wilson Inc. (2006) test results are presented in Table A-4, in which results in columns 2 and 3 are copied directly from Shannon and Wilson Inc. (2006). Note that the Shannon and Wilson Inc. (2006) results are presented in a different format than those reported by ARI tests, and the calculations of the results presented in columns 4 through 7 are not apparent. The derivations of equations for calculation of results from columns 2 and 3 to the rest of Table A-4 are given below.

The water content given in column 3 of Table A-4 is expressed as

$$\omega = \frac{M_w}{M_s + M_c} = \frac{V_w \rho_w}{V_s \rho_s + V_c \rho_c} \quad (1)$$

¹ This is a draft appendix to the sediment transport technical memorandum to be drafted later in the project.

in which ω denotes water content defined as the water mass to the combined solids and organic carbon mass ratio; M_w denotes the mass of water in the sample; M_s denotes the mass of solids in the sample; M_c denotes the dry mass of organic carbon in the sample; V_w denotes the volume of water in the sample; ρ_w denotes the density of water; V_s denotes the volume of solids; ρ_s denotes the density of solids; V_c denotes the volume of organic carbon; and ρ_c denotes the density of dry organic carbon.

The organic carbon content given in column 2 of Table 2 is expressed as

$$c = \frac{M_c}{M_s + M_c} = \frac{V_c \rho_c}{V_s \rho_s + V_c \rho_c} \quad (2)$$

in which c denotes organic carbon content defined as dry organic carbon mass to the combined solids and dry organic carbon mass ratio.

By rearranging equations (1) and (2), respectively, we obtain the following equations:

$$V_w = \omega \frac{\rho_s}{\rho_w} V_s + \omega \frac{\rho_c}{\rho_w} V_c \quad (3)$$

$$V_c = \frac{c}{1 - c} \frac{\rho_s}{\rho_c} V_s \quad (4)$$

Substituting equation (4) into equation (3) we obtain

$$V_w = \frac{\omega}{1 - c} \frac{\rho_s}{\rho_w} V_s \quad (5)$$

Based on equations (4) and (5), we obtain the following two equations:

$$f_s = \frac{V_s}{V_s + V_c + V_w} = \frac{1}{1 + \frac{c}{1 - c} \frac{\rho_s}{\rho_c} + \frac{\omega}{1 - c} \frac{\rho_s}{\rho_w}} \quad (6)$$

$$f_c = \frac{V_c}{V_s + V_c + V_w} = \frac{\frac{c}{1 - c} \frac{\rho_s}{\rho_c}}{1 + \frac{c}{1 - c} \frac{\rho_s}{\rho_c} + \frac{\omega}{1 - c} \frac{\rho_s}{\rho_w}} \quad (7)$$

in which f_s denotes the volumetric fraction of solids in the bulk sample (i.e., volume of solids as a fraction of the bulk volume of the sample, column 4 in Table A-4); and f_c denotes the volumetric fraction of the organic carbon in the bulk sample (i.e., volume of dry organic carbon as a fraction of the bulk volume of the sample, column 5 in Table A-4). The calculations from results shown in columns 4 and 5 to columns 6 and 7 in Table A-4 are apparent and simple, and thus are not presented here. Assumptions in the calculation are given beneath Table A-4.

The Shannon and Wilson Inc. (2006) test results shown in columns 6 and 7 in Table A-4 are also presented in Figures A-2 and A-3, in comparison with the ARI test results. Comparison in Figures A-2 and A-3 indicates that the results between ARI tests and Shannon and Wilson Inc. (2006) tests are consistent.

DRAFT

Using the mean value for total solid in deposit (column 7) and total organic carbon in deposit (column 8) provided in Tables A-1 through A-3, and based on the volume of deposit in reservoirs provided in GEC (2006), the amounts of solid particles and carbon in the reservoirs are summarized in Tables A-5, indicating that there is approximately 7,351,000 metric tons of solid particles and 766,000 metric tons of organic carbon in the 15,594,000 cubic meters of reservoir deposit.

Table A-1. ARI test results for Iron Gate Reservoir Samples. Data in columns 2 and 3 were extracted from Appendix E of GEC (2006)

Sample	Preserved Total Solid by Mass ^a (%)	Total Organic Carbon by Mass ^a (%)	Water Content by Mass ^b (%)	Total Solid as % of Bulk Volume of the Deposit ^c	Total Organic Carbon as % of Bulk Volume of the Deposit ^c	Total Solid in Deposit ^c (kg/m ³)	Total Organic Carbon in Deposit ^c (kg/m ³)
IG-1, S-1 ^d	63.10	2.24	34.66	39.35	3.37	1042.84	37.02
IG-1, S-1	33.20	2.24	64.56	15.83	2.57	419.59	28.31
IG1, S-1 (replicate) ^e	33.20	2.25	64.55	15.83	2.59	419.60	28.44
IG1, S-1 (replicate) ^e	33.90	2.12	63.98	16.25	2.45	430.75	26.94
IG2, S-1	28.80	2.11	69.09	13.27	2.34	351.75	25.77
IG2, S-1	28.80	2.11	69.09	13.27	2.34	351.75	25.77
IG2, S-1 (replicate) ^e	29.00	2.71	68.29	13.40	3.02	354.97	33.17
IG2, S-1 (replicate) ^e	29.30	2.60	68.10	13.56	2.90	359.42	31.89
IG3, S-1	26.40	4.42	69.18	11.98	4.83	317.46	53.15
IG4, S-1	26.20	3.76	70.04	11.86	4.10	314.36	45.11
IG5, S-1	73.60	1.64	24.76	51.41	2.76	1362.35	30.36
IG5, S-1	73.60	1.64	24.76	51.41	2.76	1362.35	30.36
IG5, S-1 (replicate)	72.80	1.54	25.66	50.38	2.57	1335.00	28.24
IG5, S-1 (replicate) ^e	72.40	1.77	25.83	49.89	2.94	1322.14	32.32
IG6, S-1	27.70	3.03	69.27	12.67	3.34	335.85	36.74
IG7, S-1	23.60	3.45	72.95	10.48	3.69	277.67	40.59
IG8, S-1	24.60	3.53	71.87	11.00	3.80	291.60	41.84
IG-9, S-1	33.20	1.44	65.36	15.82	1.65	419.21	18.18
Mean	36.34	2.67	60.99	19.91	3.11	527.63	34.20
Standard Deviation	18.67	1.01	18.08	15.67	0.93	415.14	10.23
Maximum	73.60	4.42	72.95	51.41	4.83	1362.35	53.15
Minimum	23.60	1.44	24.76	10.48	1.65	277.67	18.18

- ARI test data termed as “preserved total solids” and “total organic carbon”;
- Calculated by assuming that the majority of the sample mass is composed of solids, organic carbon and water, representing minimum water contents due to potential water loss during the handling of the samples (Agnes Tirao and Dennis Gathard, personal communication, 2 November 2007);
- Calculated based on the assumed density for water, solids, and dry organic carbon of 1,000 kg/m³, 2,650 kg/m³, and 1,100 kg/m³, respectively;
- Excluded in calculating mean, standard deviation, and maximum minimum values because of its discrepancy with the other three test for the same sample;
- Excluded in calculating mean, standard deviation, and maximum and minimum values because they are replicates;

Table A-2. ARI test results for Copco 1 Reservoir Samples. Data in columns 2 and 3 were extracted from Appendix E of GEC (2006)

Sample	Preserved Total Solid by Mass ^a (%)	Total Organic Carbon by Mass ^a (%)	Water Content by Mass ^b (%)	Total Solid as % of Bulk Volume of the Deposit ^c	Total Organic Carbon as % of Bulk Volume of the Deposit ^c	Total Solid in Deposit ^c (kg/m ³)	Total Organic Carbon in Deposit ^c (kg/m ³)
C-1, S-1	80.30	0.39	19.31	60.64	0.71	1607.08	7.79
C-10, S-1	24.00	3.67	72.33	10.69	3.94	283.28	43.32
C-11, S1	34.70	2.48	62.82	16.75	2.88	443.91	31.73
C-12, S-2C/3C	35.00	16.20	48.80	17.21	19.19	456.12	211.12
C-12, S-2C/3C	23.40	8.33	68.27	10.43	8.94	276.36	98.38
C-12, S-2C/3C (replicate) ^d	23.40	6.60	70.00	10.41	7.07	275.85	77.80
C-12, S-2C/3C (replicate) ^d	23.40	6.94	69.66	10.41	7.44	275.95	81.84
C-2, S-1	23.10	4.48	72.42	10.23	4.78	271.10	52.58
C-3, S-1	24.20	3.44	72.36	10.79	3.70	285.99	40.65
C-4, S-1	20.00	3.92	76.08	8.66	4.09	229.38	44.96
C-5, S-1	24.00	3.68	72.32	10.69	3.95	283.28	43.44
C-6, S-1	23.40	8.33	68.27	10.43	8.94	276.36	98.38
C-7, S-1	50.00	1.56	48.44	27.45	2.06	727.53	22.70
C-8, S-1	21.10	5.03	73.87	9.22	5.29	244.20	58.21
C9, S-1	22.50	4.06	73.44	9.92	4.31	262.78	47.42
C-9, S-1	22.50	4.06	73.44	9.92	4.31	262.78	47.42
C-9, S-1 (replicate) ^d	22.50	3.24	74.26	9.91	3.44	262.56	37.81
C-9, S-1 (replicate) ^d	22.60	2.64	74.76	9.95	2.80	263.75	30.81
Mean	30.59	4.97	64.44	15.93	5.51	422.15	60.58
Standard Deviation	16.42	3.88	15.70	13.81	4.53	365.95	49.79
Maximum	80.30	16.20	76.08	60.64	19.19	1607.08	211.12
Minimum	20.00	0.39	19.31	8.66	0.71	229.38	7.79

a. ARI test data termed as “preserved total solids” and “total organic carbon”;

b. Calculated by assuming the majority of the sample mass is composed of solids, organic carbon and water, representing minimum water contents due to potential water loss during the handling of the samples (Agnes Tirao and Dennis Gathard, personal communication, 2 November 2007);

c. Calculated based on the assumed density for water, solids, and dry organic carbon of 1,000 kg/m³, 2,650 kg/m³, and 1,100 kg/m³, respectively;

d. Excluded in calculating mean, standard deviation, and maximum and minimum values because they are replicates.

Table A-3. ARI test results for J.C. Boyle Reservoir Samples. Data in columns 2 and 3 were extracted from Appendix E of GEC (2006)

Sample	Preserved Total Solid by Mass ^a (%)	Total Organic Carbon by Mass ^a (%)	Water Content by Mass ^b (%)	Total Solid as % of Bulk Volume of the Deposit ^c	Total Organic Carbon as % of Bulk Volume of the Deposit ^c	Total Solid in Deposit ^c (kg/m ³)	Total Organic Carbon in Deposit ^c (kg/m ³)
J-1, S-1	16.00	7.46	76.54	6.76	7.59	179.05	83.48
J-1, S-1	16.00	7.46	76.54	6.76	7.59	179.05	83.48
J-1, S-1 (replicate) ^d	16.10	6.36	77.54	6.80	6.47	180.09	71.14
J-1, S-1 (replicate) ^d	16.10	6.21	77.69	6.79	6.31	180.07	69.45
J-3, S-1	74.20	1.24	24.56	52.15	2.10	1382.08	23.10
J-4, S-1	29.40	4.67	65.93	13.65	5.22	361.76	57.46
J-5, S-1	40.20	4.56	55.24	20.35	5.56	539.20	61.16
Mean	35.16	5.08	59.76	19.93	5.61	528.23	61.74
Standard Deviation	24.07	2.57	21.57	18.87	2.25	500.19	24.79
Maximum	74.20	7.46	76.54	52.15	7.59	1382.08	83.48
Minimum	16.00	1.24	24.56	6.76	2.10	179.05	23.10

- a. ARI test data termed as “preserved total solids” and “total organic carbon”;
- b. Calculated by assuming the majority of the sample mass is composed of solids, organic carbon and water, representing minimum water contents due to potential water loss during the handling of the samples (Agnes Tirao and Dennis Gathard, personal communication, 2 November 2007);
- c. Calculated based on the assumed density for water, solids, and dry organic carbon of 1,000 kg/m³, 2,650 kg/m³, and 1,100 kg/m³, respectively;
- d. Excluded in calculating mean, standard deviation, and maximum and minimum values because they are replicates.

Table A-4. Shannon and Wilson Inc. (2006) test results for reservoir deposit Samples. Data in columns 2 and 3 were reported in Shannon and Wilson Inc. (2006) and GEC (2006)

Sample ^a	Amount of Organic Carbon as % of Solid and Dry Organic Carbon Mass ^b	Water Content as % of Solid and Dry Organic Carbon Mass ^c	Total Solid as % of Bulk Volume of the Deposit ^d	Total Organic Carbon as % of Bulk Volume of the Deposit ^d	Total Solid in Deposit ^d (kg/m ³)	Total Organic Carbon in Deposit ^d (kg/m ³)
J-1, S-5	12.50	304.10	9.48	3.26	251.22	35.86
IG9, S-2	7.70	107.40	23.34	4.69	618.51	51.59
C-6, S-5	12.70	330.30	8.79	3.08	232.94	33.88
C-2, S-4	15.50	228.30	11.63	5.14	308.20	56.54
C-4, S-6	10.30	238.40	10.36	2.87	274.54	31.57

- a. J denotes J.C. Boyle Reservoir, IG denotes Iron Gate Reservoir, and C denotes Copco 1 Reservoir;
- b. Reported in Shannon and Wilson Inc. (2006) and GEC (2006), termed as “organic content”;
- c. Reported in Shannon and Wilson Inc. (2006) and GEC (2006), termed as “water content”;
- d. Calculated based on the assumed density for water, solids, and dry organic carbon of 1,000 kg/m³, 2,650 kg/m³, and 1,100 kg/m³, respectively.

Table A-5. Summary of reservoir deposit by content

Reservoir	Volume of Deposit (m³)^a	Solid in Deposit (Metric tons)^b	Carbon in Deposit (Metric tons)^c
Iron Gate	6,790,000	3,583,000	232,000
Copco 1	8,318,000	3,511,000	504,000
J.C. Boyle	486,000	257,000	30,000
Total	15,594,000	7,351,000	766,000

a. Based on Tables 13 through 15 in GEC (2006), approximated to the nearest thousand cubic meters;

b. Based on volume in column 2 and mean total solid presented in Tables A-1 through A-3;

c. Based on volume in column 2 and mean organic carbon presented in Tables A-1 through A-3.

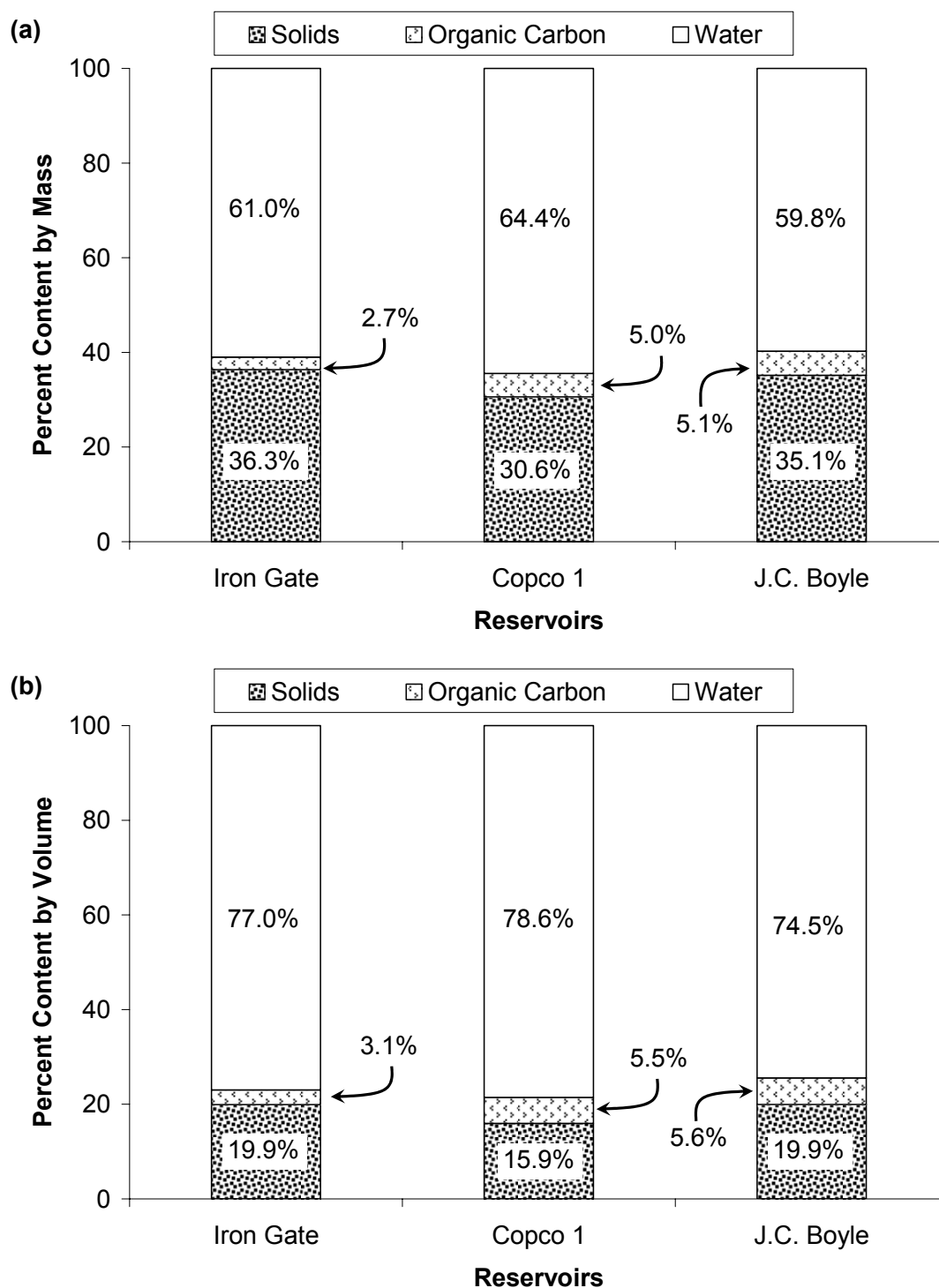


Figure A-1. Primary composition of the deposits in Iron Gate, Copco 1, and J.C. Boyle reservoirs, based on the mean value of the ARI test data: (a) by mass; and (b) by volume.

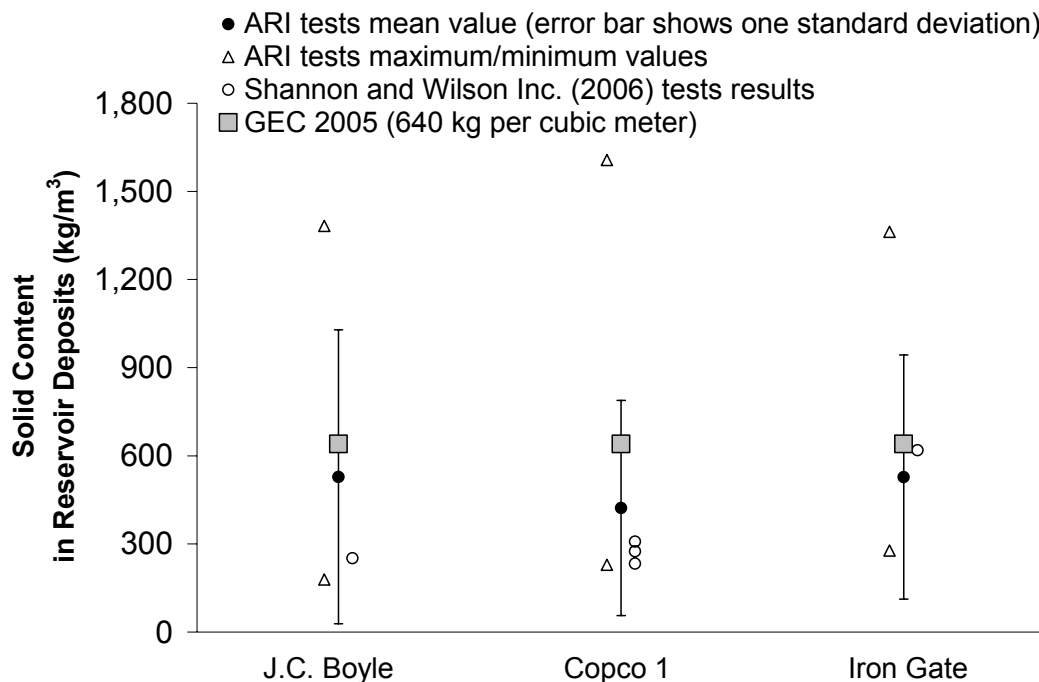


Figure A-2. Solid content in reservoir deposits based on ARI tests (GEC 2006) and Shannon and Wilson Inc. (2006) tests.

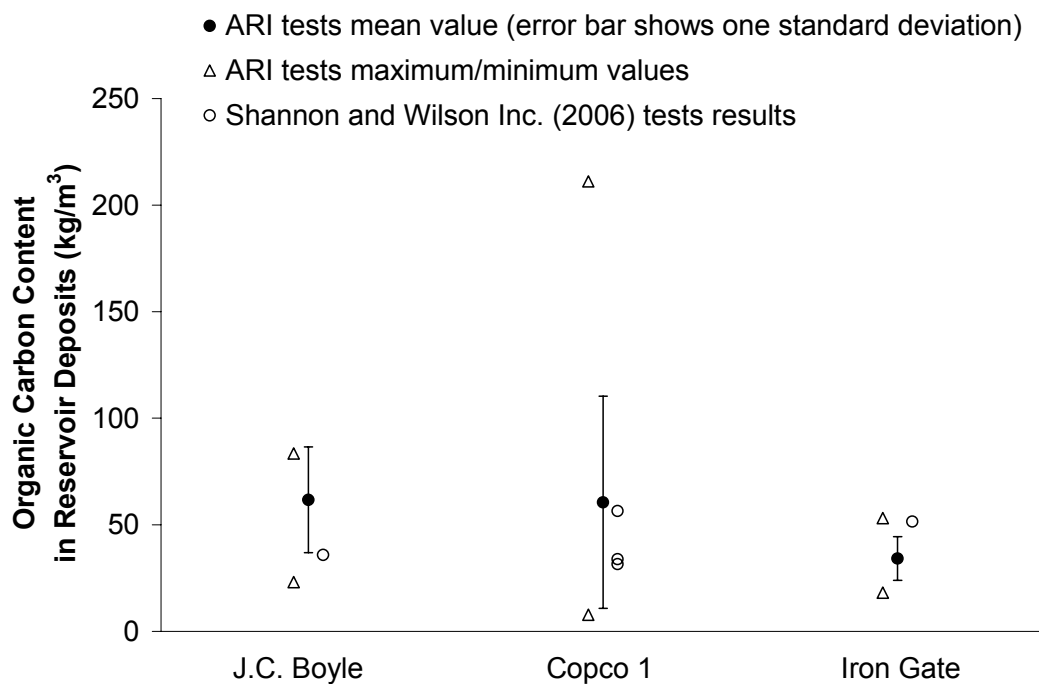


Figure A-3. Organic carbon content in reservoir deposits based on ARI tests (GEC 2006) and Shannon and Wilson Inc. (2006) tests.